CHAPTER 1
INTRODUCTION

1.1 Background of Study

The common coating in the market nowadays is made by binder and synthetic polymer that are not environmental friendly and detrimental which impacts the sustainability of the nature. Due to this fact many researches have been done to provide an alternative coating that content less volatile organic compound (VOC).

The Volatile Organic Compound (VOC) in the coating can cause pollution to the indoor and outdoor environment. In term of definition Volatile organic compounds (VOC) are gases or vapors emitted by various solids or liquids which have short and long term adverse health effects. It can evaporate to the atmosphere in the room temperature and contribute to the thinning of the ozone layer.

Coating compositions are made by chemical polymer substances content carcinogenic element that can harm human's health since it can cause lung cancer. People are breathing by using air in the environment. So, polluted air will cause many health problems to human being. Therefore it is our responsibility to ensure good quality of air by reduces or remove pollution sources.

Growing concerns over the environmental impact of solid waste disposal have increased the interest in biodegradable polymers in recent years. Because of its low cost, biodegradability and renew ability, starch has been investigated as filler and extender is the reduction in yield and tensile strength as starch content is increased, but use of small quantity of starch improves the interfacial strength due to mechanical

interlocking between adjacent layers. There are a lot of biopolymer sources such as starch from plants and microorganism that can produce polymers. There were projects had been conducted involved the potato starch and exopolysaccharides as component in biopolymer coating. The result showed the anti corrosive behavior. In this project, biopolymers coating made by tapioca will be used to create a tapioca polysaccharides based coating.

Coating is widely use as primary corrosion prevention method. It was said that with good coating, better than 90 percent of carbon steel surface would be completely free of corrosion. Green technology coating will introduce new evolution in coating industry that protects material, environmental friendly and economical.

The effectiveness of tapioca polysaccharides based coating was determined through experiment in laboratory using the ASTM standard. All the data gather and scientific analysis conducted to study the corrosion protective behavior and present in proper documentation. Tapioca polysaccharides based coating is a new finding for coating application world wide. It is not only protecting the steel from corrosion but also the environment and safe for human's life. The project was a preliminary investigation to study the anti corrosion behavior of tapioca polysaccharides.

Since Malaysia is a tropical country, it is rich with polysaccharides sources such as tapioca. Tapioca polysaccharides can be implemented widely due to the high availability and cheaper than chemical substances used currently.

1.2 Problem Statement

The problem is coating production involves chemical substances content volatile organics compound (VOC) that easily can vaporize and enter the atmosphere. It cause indoor and outdoor pollution and detrimental to the environment. Beside, the carcinogenic element can cause lung cancer from the air that polluted with the VOC

element. The chemical substances are made by nonrenewable sources and the cost of manufacturing is expensive.

Polysaccharides are application of green and environmental friendly technology from renewable sources. It can reduce the Volatile organics compounds (VOC) content in coating compositions. An engineering approach design to investigate the effectiveness of tapioca polysaccharides based coating using the ASTM standards.

1.3 Objectives of study

The objectives of this work are:

1. To study the effectiveness of tapioca polysaccharides for based coating to protect carbon steel from corrosion attack.

The scopes of studies would be on towards the various coating tests which include determination of the adhesion strength and corrosion prevention performance. All results from the tests will be analyzed to prove the suitability and effectiveness tapioca polysaccharides as alternative material in coating manufacturing industry.

CHAPTER 2
LITERATURE REVIEW AND THEORY

Review for the study was taken abundantly from thesis, journals, reference books and the internet.

2.1 Corrosion Process

The corrosion of carbon steel and its alloys cause severe economical loss resulting in a yearly cost of billion dollars loss. Corrosion is chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties.

There are certain conditions, which must be met before corrosion can function. There are:

1. There must be an anode
2. There must be cathode
3. They must be metallic path electrically connecting the anode and cathode
4. The anode and cathode must be immersed in an electrically conductive electrolyte which is ionized.

In the gas pipeline for the example, the natural corrosion process happen because pipelines exposed with the natural environment. The natural corrosion rate is high compared to other places [11].

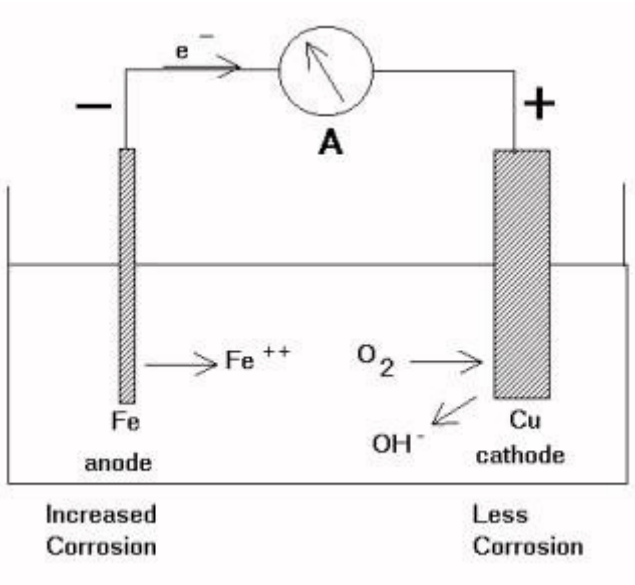


Figure 2.1: Corrosion Process [11]

Once these conditions are met, an electric current will flow and metal will consumed at the anode. Referring to the **figure 2.1**, the pressure exerted by the potential difference between the anode and cathode results in the migration of electrons from anode to cathode along the metallic connection between anode and cathode.

2.1.1 Corrosion Prevention

2.1.1.1 Coatings

Coatings is the most popular method to prevent corrosion. Coatings usually are inorganic paints that are applied on cleaned surface. However, for special applications, vacuum coatings can be applied to prevent corrosion, Example of coating such as TiN, CrN.

2.1.1.2 Materials Selection

Materials selection is the first steps to eliminate or minimize corrosion. The following rule can help as initial guidelines for materials selection for corrosion prevention concerns:

1. Avoid dissimilar metals to prevent galvanic corrosion.
2. Select materials with compact insulating oxide or passive layer such as stainless

steel or aluminum.
3. Avoid the usage of materials with localized nonuniform stresses by stress relief Heat Treatment process.

2.1.1.3 Cathodic Protection

Cathodic protection is to apply either a sacrificial anode (usually zinc) or cathodic current from power supply to suppress the anodic reaction on the protected element.

2.1.1.4 Anodic Protection

Anodic protection is used to take advantage of the I-V curve of the protected parts to apply potential in the range of the passive current. However, this technique can be applied to few materials, such as Cr, Al, with precise control of the applied potential.

2.1.1.5 Corrosion Inhibitor

2.1.1.5.1 Gas Phase Corrosion Inhibitor

Gas Phase Corrosion Inhibitors are materials that have relatively high vapor pressure which can sublimate and adsorb on metal surfaces. Upon adsorption the material will form a chemical bond with the surface to change its surface state toe prevent or to add a large activation barrier to the anodic reaction. The example such as Benzotriazole (BTA) or copper surface.

2.1.1.5.2 Liquid Phase Corrosion Inhibitors

Liquid Phase Corrosion Inhibitors are additive usually added to aqueous solutions to prevent corrosion in the liquid phase. Several industrial processes uses the liquid corrosion inhibitors, e.g. boilers, cooling liquids in machining, oil pipelines and equipments.

2.1.1.6 Electroplating

Electroplating is very common method to coat surfaces to prevent corrosion. Zn is one of the most popular methods to prevent corrosion on steel. Ni/Cu is a common plating metal for corrosion protection.

2.2 Coating

Coating can be used to improve the surface properties of material and long life the age. Normally it uses to improve the appearance, adhesion, wet ability, corrosion resistance, wear resistance, and scratch résistance. There are many types of coating in the market such as inorganic zinc primer and epoxy zinc rich primer.

The compositions of coating normally are binder, pigment extender, solvent and additive. Coating also is made by synthetic polymers that are not renewable, not biodegradable, and some are also known as very toxic, even carcinogenic and last but not least can cause enormous environmental damage [2].

2.2.1 Fusion Bonded Epoxy Coating

Fusion bonded epoxy coating, also known as fusion-bond epoxy powder coating and commonly referred to as FBE coating, is an epoxy based powder coating that is widely used to protect steel pipe used in pipeline construction, concrete reinforcing bars (rebar) and on a wide variety of piping connections, valves etc. from corrosion. FBE coatings are thermo set polymer coatings.

They come under the category of 'protective coatings' in paints and coating nomenclature. The name 'fusion-bond epoxy' is due to resin cross-linking and the application method, which is different from a conventional paint. The resin and hardener components in the dry powder FBE stock remain unreacted at normal storage conditions. At typical coating application temperatures, usually in the range of 180 to 250 °C (360 to 480 °F), the contents of the powder melt and transform to a liquid form.

The liquid FBE film wets and flows onto the steel surface on which it is applied, and soon becomes a solid coating by chemical cross-linking, assisted by heat. This process is known as “fusion bonding”. The chemical cross-linking reaction taking place in this case is irreversible. Once the curing takes place, the coating cannot be returned to its original form by any means. Application of further heating will not “melt” the coating and thus it is known as a “thermo set” coating. The world's leading FBE manufacturers are KCC Corporation, Jotun Powder Coatings, 3M, DuPont, Akzo Nobel, BASF and Rohm & Haas.

2.2.2 Epoxy Resin

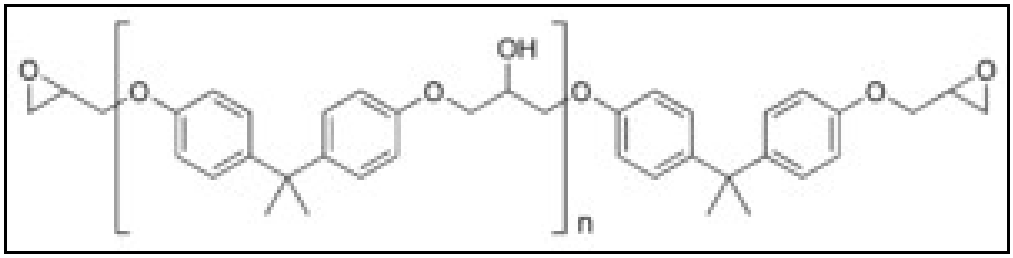


Figure 2.2: Structure of unmodified Bisphenol A [13]

Epoxy or polyepoxide is a thermosetting epoxide polymer that cures (polymerizes and crosslinks) when mixed with a catalyzing agent or "hardener". Most common epoxy resins are produced from a reaction between epichlorohydrin and bisphenol-A. The **figure 2.2** is referring the polymer structure of Bisphenol A.

The applications for epoxy based materials are extensive and include coatings, adhesives and composite materials such as those using carbon fiber and fiberglass reinforcements. The chemistry of epoxies and the range of commercially available variations allow cure polymers to be produced with a very broad range of properties. In general, epoxies are known for their excellent adhesion, chemical and heat resistance, good to excellent mechanical properties and very good electrical insulating properties, but almost any property can be modified (for example silver-filled epoxies with good electrical conductivity are available, although epoxies are typically electrically insulating).

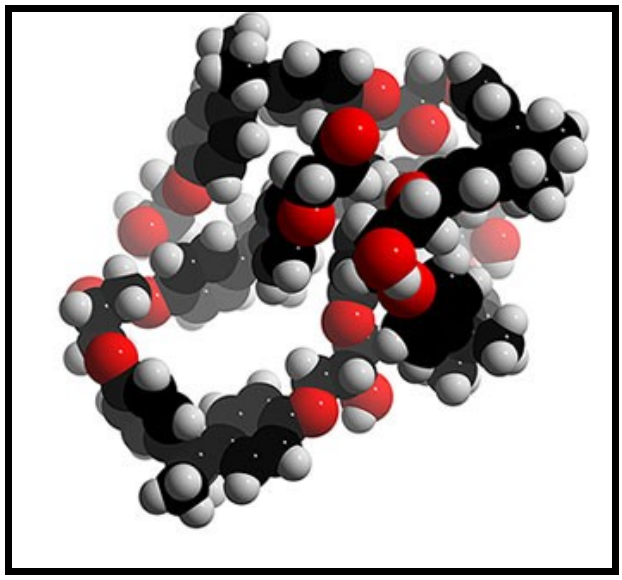


Figure 2.3: 3D model of the Epoxy Resin structure [11]

The main function of epoxy or polyepoxide is to cures the polymer for polymerizes and cross links when mix with hardener. Reaction between epicholorohydrin and bisphenol-A is common method to produce epoxy resins. It characteristics are very strong, tough, water resistance and capable to bond together wide range of materials including woods, composites and polymers. The **figure 2.3** is referring to the 3D model of the epoxy resin structure to give wider understanding.

Their low VOC and water clean up makes them a natural choice for factory cast iron, cast steel, cast aluminums applications and reduces exposure and flammability issues associated with solvent borne coatings. Besides that, epoxy coating also being used for primers to improve the adhesion properties. Fusion Bonded Epoxy Powder Coatings are extensively applied to protect pipelines in oil and gas industry.

Table 2.1: Multifunctional Epoxy Resins [13]

Product Resin / Hardener	Description	Coulour	Applications	Viscosity (mPa.s)	Pot life (mn)	Tg (°c)*
Multifunctional resins						
EPOLAM 2010/2010	Versatile epoxy system with a single resin and choice of 3 hardeners. Variable curing time.		Composite moulds and parts. Can be used as a gelcoat, on casting resins or concrete, with additional fillers.	1000	30'-35'	50
EPOLAM 2010/2011				900	60'-70'	50
EPOLAM 2010/2012				800	120'-150'	55
EPOLAM 2050	Temperature resistant. Good wettability.		Composite moulds. Concrete or casting.	2000	60'	125
EPOLAM 2025	Good mechanical properties. Can be used for moulds up to 135°C after curing.		Moulds with good temperature resistance by wet lay-up.	1400	70'	135
EPOLAM 2001/95B	Multi-functional, low viscosity epoxy system. Variable reactivity (choice of 2 hardeners).		EPOLAM 2001 can be used to mould parts that require moulds with a degree of flexibility and impact strength.	400	70'	50
EPOLAM 2001/95S				600	40'	55
EPOLAM 2002	Epoxy system for moulds. Weak odour and dimensional stability.		For producing concretes and laminates in the ceramics industry.	950	55'	65

Table 2.2: The Properties of Epolam 2050 [13]

References	description	viscosity (mPa.s)	pot life mn	hardness shore	Tg (°c)	applications
EPOLAM 2050	Heat resistant. Good wetting.	2000	70-90	87	125	Tooling for composites. Concrete or casting.

There are a lot of epoxy resins in the market currently with different usage. The **table 2.1** is referring to the properties of different kind of epoxy and its application. The **table 2.2** is referring to the properties of Epolam 2050 that will be used in this project.

2.2.3 Coating Environment Issue

The coating contain the volatile organic compound (VOC).The VOC are sometimes accidentally released into the environment, where they can damage soil and groundwater. Vapours of VOCs escaping into the ambient air contribute to indoor air pollution and outdoor air pollution.

2.2.3.1 Contribution to outdoor air pollution

VOCs are an important outdoor air pollutant. In this field they are often divided into the separate categories of methane (CH_4) and non-methane (NMVOCs). Methane is an extremely efficient greenhouse gas which contributes to enhance global warming. Other hydrocarbon VOCs are also significant greenhouse gases via their role in creating ozone and in prolonging the life of methane in the atmosphere, although the effect varies depending on local air quality [10].

2.2.3.2 Contribution to indoor air pollution

Many consumer products found around the house, such as cleaning solvents, paints, and wood preservatives from certain furniture all emit VOC compounds, which may contribute to sick building syndrome and other effects such as allergic sensitization or asthmatic symptoms. Due to the high abundant use of VOC-containing products indoors and the high vapor pressure of VOCs, these compounds can easily off-gas into the indoor environment. They also occur in and are released from most common indoor materials from natural sources such as trees, animals, and plants as well as from synthetic sources such as petroleum derivatives.

The aromatic VOC compound benzene, emitted from exhaled cigarette smoke is labeled as carcinogenic, and is ten times higher in smokers than in nonsmokers. Good ventilation and air conditioning systems are helpful at reducing VOC emissions in the indoor environment. Studies also show that relative leukemia and lymphoma can increase through prolonged exposure of VOCs in the indoor environment. According

one review article, most of the non-methane VOC compounds are produced by plants and trees in our ecological environment.

Relative humidity within an indoor environment can also affect the emissions of VOCs and formaldehyde. In fact, high relative humidity and high temperature allow more vaporization of formaldehyde from wood-materials and thus, can induce symptoms of sensory irritation in the eyes

The definitions of VOCs used for control of precursors of photochemical smog used by EPA and states with their own outdoor air pollution regulations includes exemptions for compounds that are technically only those volatile organic compounds but that are determined to be non-reactive or of low-reactivity in the smog formation process. EPA formerly defined these compounds as Reactive Organic Gases (ROG) but changed the terminology to VOC for simplicity's sake. However, this specific use of the term VOCs can be misleading, specifically when applied to indoor air quality because many chemicals that are not regulated for purposes of controlling outdoor air pollution but that are important from an indoor air quality perspective are still found in products that are labeled as to VOC content according to the requirements of ambient air pollution regulation.

In recent years many common materials and products used indoors have been developed and are labeled by their manufacturers as "low VOC" or "zero VOC content" and other similar terms. While some of these products may actually have low VOC content in the broader definition of VOC relevant to indoor air, some products so labeled may actually have larger VOC content but the VOCs contained in them may be exempt from the EPA's definition [13]

2.3 Biopolymers

Biopolymers are a class of polymers produced by living organisms such as Starch, proteins and peptides. It’s formed by multi links of sugars, amino acids and nucleotides. The things differentiate biopolymer and polymer is their structures. Both are made by repetitive units of monomers. Generally, the exact chemical composition and unit of cells arrangement in polymer is called primary structure.

The advantages of biopolymers

- Biopolymers have compact and complicated shapes of structure which determine their biological functions depend on the primary structure
- In facts biopolymers are renewable
- In facts biopolymers can be carbon neutral
- In facts biopolymers are biodegradable
- In facts biopolymers are compost able.

Many biopolymers investigated do have anti-corrosive properties. Biopolymer layers formed are subject of further research. In the future research the most suitable and effective biopolymer candidates will be applied in paint and coating formulation will be optimized. The biopolymers that have been tested the effectiveness is exopolysaccharides produced by GRAS (Generally Recognized As Safe) lactic acid bacteria and in this project tapioca polysaccharides will be tested [2.].The **figure 2.4** is referring to the Exopolysaccharides (EPS).

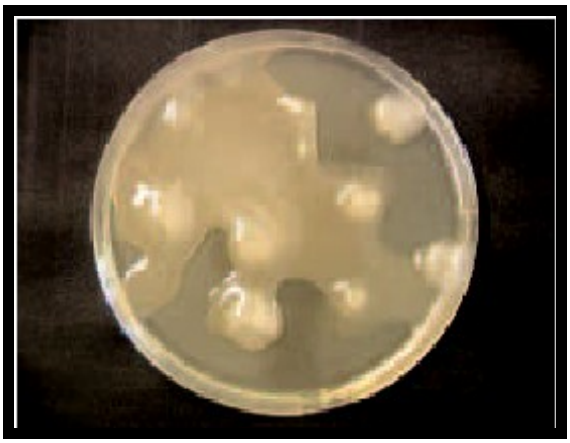


Figure 2.4: Exopolysaccharides (EPS) produced by lactic acid bacteria[2]

2.4 Polysaccharides

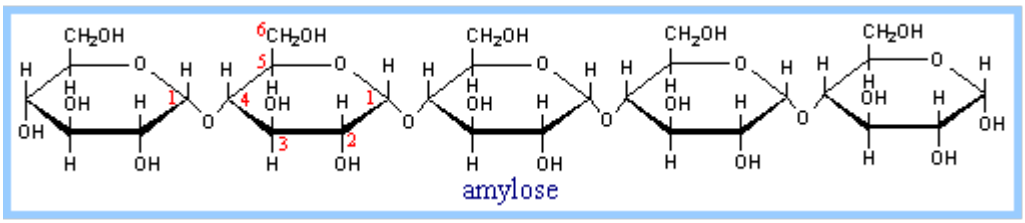


Figure 2.5: Polysaccharides from plant, Amylose [13]

Polysaccharides from natural sources have generated remarkable interest as biotechnological product and commercial uses in wide range of industrial applications. Some of them are showing strong antigenic and pathogenic activities. Polysaccharides, for their unusual multiplicity and structural complexity, contain many biological messages and accordingly they may perform several functions. Moreover, these biopolymers have the ability to interact with other polymers such as proteins, lipids. The **figure 2.5** is referring to Polysaccharides structure from plant.

Polysaccharides are relatively complex carbohydrates. They are polymers made up of many monosaccharide joined together by glycosides bonds. Therefore there are very large, often branched, macromolecules. They tend to be amorphous, insoluble in water, and have no sweet taste. These polysaccharides can be obtained from plant and this study is focus on tapioca polysaccharides.

Polysaccharides have a general formula of $C_n(H_2O)_{n-1}$ where n is usually a large number between 200 and 2500. Considering that the repeating units in the polymer backbone are often six-carbon monosaccharide, the general formula can also be represented as $(C_6H_{10}O_5)_n$ where n={40...3000}.

Bacteria and many other microbes, including fungi and algae, often secrete polysaccharides as an evolutionary adaptation to help them adhere to surfaces and to prevent them from drying out. Humans have developed some of these polysaccharides into useful products, including xanthan gum, dextran, gellan gum, and pullulan.

Homopolysaccharides produced by lactic acid bacteria are often synthesized by a single extra cellular sucrose enzyme using only sucrose as substrate [].They can be produced in larges quantities. Moreover, their structure can be modified allowing optimization of their physicochemical properties.

By means of cyclic voltanmmetry, impedance measurements and potential monitoring, the electrochemical behavior of this new type of anti-corrosive

biopolymers has been studied [11]. **Figure 2.6** is referring to the different Structures of polysaccharides.

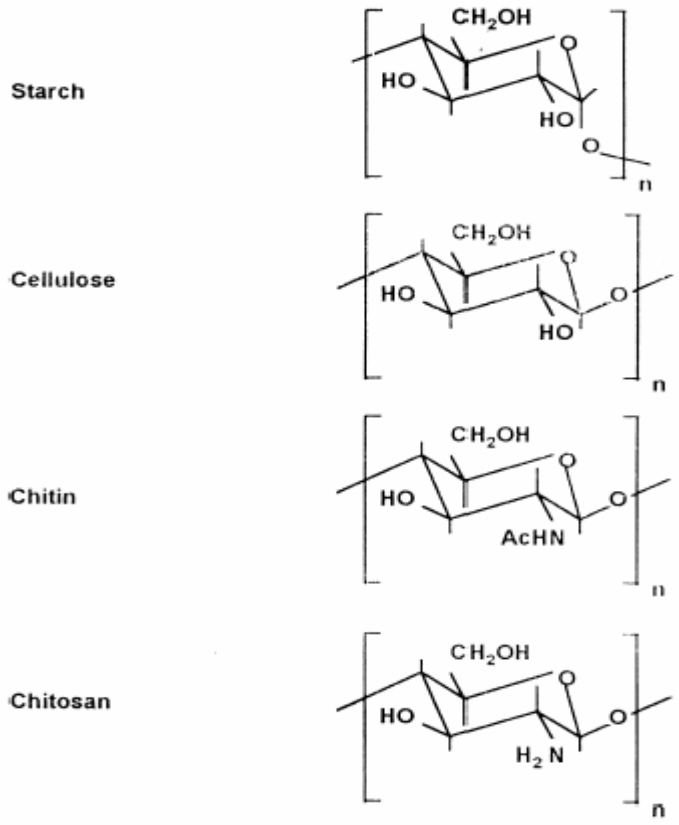


Figure 2.6: Structures of polysaccharides [13]

2.3.1 Extraction and Isolation of Tapioca Polysaccharides [9]

1. One kg of the dried and cut raw tapioca was extracted with methanol or ethanol overnight, and then separated by centrifugation. The methanol or ethanol extraction process was carried out three times.
2. The precipitate was dried in a hot air oven, and then added with deionised water and held at 4° C. overnight to subject the precipitate to cold infiltration. The resultant mixture was heated to 100° C. and boiled for two hours.
3. A supernatant solution was obtained by centrifuging the mixture, and the supernatant solution was then subjected to a chloroform (1/5 volume) and 1-butanol (1/15 volume) de-protein zing process for three times.

4. Thereafter, the tapioca polysaccharide was recrystallized from the de proteinzed supernatant solution using ethanol. The orally active tapioca polysaccharides Galu© were obtained there from by lyophilizing the re-dissolved polysaccharide-containing solution.
5. For comparison with conventional alkaline extraction of these polysaccharides, the tapioca polysaccharide Galu© were solubilized in 0.5N NaOH and stirred overnight at room temperature, then adjusted to pH 7.0 and dialyzed overnight at 4° C. The resultant polysaccharide-containing solution was subjected to lyophilization so as to obtain Galu(N)

2.5 Polymer Blend

Two polymers can be blend by heating the both two polymers together until there are above the glass transition temperatures of both polymers. At this point they will be nice and gooey, and can mix them together like a cake mix. This is often done in machines such as extruders. When done, it will be a nice blend, again, presuming your two polymers are miscible.

2.5.1 Properties of Blends

In general, a miscible blend of two polymers is going to have properties somewhere between those of the two unblended polymers. Take for example the glass transition temperature, or T_g for short. Take polymer A and blend it with polymer B, the T_g will depend on the ratio of polymer A to polymer B in the blend. It is shown in the graph **figure 2.7** below.

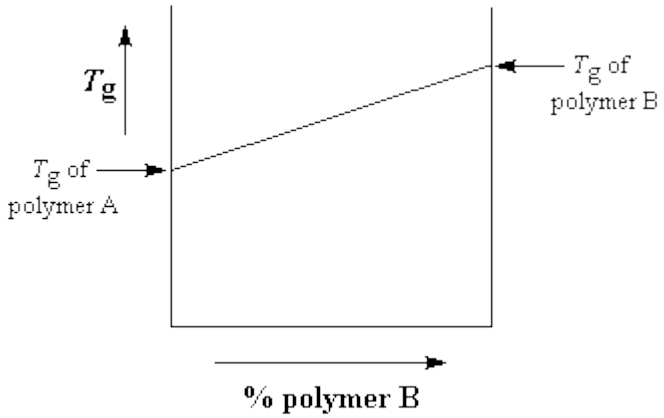


Figure 2.7: Polymer Blend T_g

If polymer B has a higher T_g than polymer A, the T_g of the blend is going to increase as the relative amount of polymer B in the blend increases. The increase is generally linear, as seen in the graph. But the plot is not perfectly linear. Sometimes if the two polymers bind more strongly to each other than to themselves, the T_g will be higher than expected, because the stronger binding lowers chain mobility. The plot will look like you see in the graph **figure 2.8** on the right below.

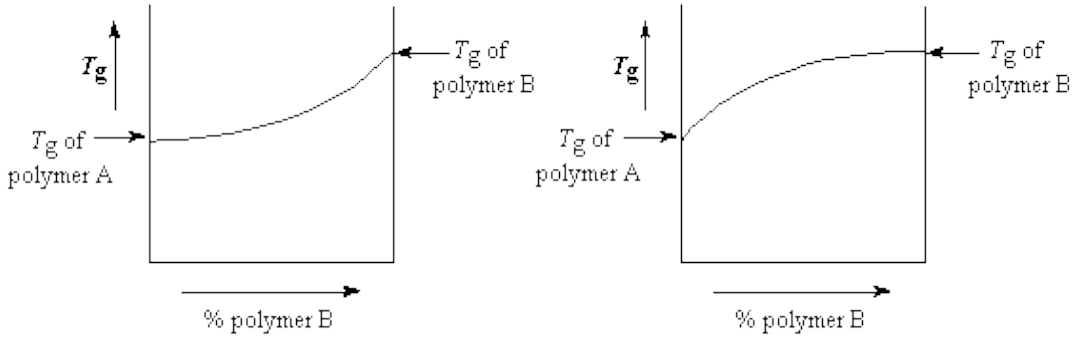


Figure 2.8: Temperature Glass Transition of Two Polymers

Of course, in most cases, the two polymers bind less strongly with each other than with themselves, so the T_gs of the blends are usually a little lower than expected. The T_g plot will look like the one you see above on the left.

Why T_gs is important and discussed up until now, It is because T_gs generally holds for other properties. Mechanical properties, resistance to chemicals, radiation, or heat; they all generally plot the same way as the T_g does with respect to the relative amounts of each polymer in the blend.

2.6.2 Non Mix Polymers

A few polymer pairs mix. Most do not. But there are also polymer pairs that sometimes mix and sometimes don't. The variables that one can control to make them mix or not mix are usually temperature and composition. A lot of polymer pairs are only miscible when there is a lot more of one polymer than of the other. There will be a range of compositions for which the two polymers won't mix. For example, let's say two polymers, polymer A and polymer B. They are miscible when have less than 30%

polymer B, that they are miscible when there is more than 70% polymer B. But between 30 and 70% polymer B, the blend phase-separates into two phases. The **figure 2.9** is show the process.

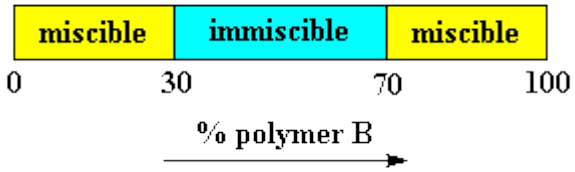


Figure 2.9: Miscible Polymers

Interestingly, one phase will have 30% polymer B and the other will have 70% polymer B. There is a reason for this. Look at a plot of free energy versus composition; we will see that these two compositions are lower in energy than any other compositions. One note first: it is usually use the Greek letter f to represent the relative amount of one or the other component in a mixture of any kind, so it will be going to use f_B instead of "% B" from here on.

2.6 Laboratory Test for Coating System

2.6.1 Adhesion Testing (ASTM D3359)

For coatings to perform satisfactorily, they must adhere to the substrates on which they are applied. A variety of recognized methods can be used to determine how well a coating is bonded to the substrate. Commonly used measuring techniques are performed with a knife or with a pull-off adhesion tester. After any test it is important to record if the bond failure was adhesive (failure at the coating / substrate interface) or cohesive (failure within the coating film or the substrate).

2.6.1.1 Knife Test

This simple test requires the use of a utility knife to pick at the coating. It establishes whether the adhesion of a coating to a substrate or to another coating (in multi-coat systems) is at a generally adequate level. Performance is based on both the degree of difficulty to remove the coating from the substrate and the size of removed coating.

Using the knife and cutting guide, two cuts are made into the coating with a 30 – 45 degree angle between legs and down to the substrate which intersects to form an "X". At the vertex, the point of the knife is used to attempt to lift up the coating from the substrate or from the coating below.

This is a highly subjective test and its value depends upon the inspector's experience. A coating which has a high degree of cohesive strength may appear to have worse adhesion than one which is brittle and hence fractures easily when probed. There is no known correlation to other adhesion test methods (pull-off, tape, etc.).

A standard method for the application and performance of this test is available in ASTM D6677.

2.6.1.2 Tape Test

On metal substrates, a more formal version of the knife test is the tape test. Pressure sensitive tape is applied and removed over cuts made in the coating. There are two variants of this test; the X-cut tape test and the cross hatch tape test.

The X-cut tape test is primarily intended for use at job sites. Using a sharp razor blade, scalpel, knife or other cutting device, two cuts are made into the coating with a 30 – 45 degree angle between legs and down to the substrate which intersects to form an "X". A steel or other hard metal straightedge is used to ensure straight cuts. Tape is placed on the center of the intersection of the cuts and then removed rapidly. The X-cut area is then inspected for removal of coating from the substrate or previous coating and rated.

The cross hatch tape test is primarily intended for use in the laboratory on coatings less than 5 mils (125 microns) thick. It uses a cross-hatch pattern rather than the X pattern. A cutting guide or a special cross-hatch cutter with multiple preset blades is needed to make sure the incisions are properly spaced and parallel. After the tape has been applied and pulled off, the cut area is then inspected and rated.

A standard method for the application and performance of these tests is available in ASTM D3359.

2.6.1.3 Pull-Off Tests

Figure 2.10: Pull Off Test Equipment

A more quantitative test for adhesion is the pull-off test where a loading fixture, commonly called a dolly or stub, is affixed by an adhesive to a coating. By use of a portable pull-off adhesion tester shown in the **figure 2.10**, a load is increasingly applied to the surface until the dolly is pulled off. The force required to pull the dolly off or the force the dolly withstood, yields the tensile strength in pounds per square inch (psi) or mega Pascals (MPa). Failure will occur along the weakest plane within the system comprised of the dolly, adhesive, coating system, and substrate, and will be exposed by the fracture surface.

This test method maximizes tensile stress as compared to the shear stress applied by other methods, such as scrape or knife adhesion, and results may not be comparable. Further, pull-off strength measurements depend upon the instrument used in the test. Results obtained using different devices or results for the same coatings on substrates having different stiffness may not be comparable.

Testers operate using mechanical (twist by hand), hydraulic (oil) or pneumatic (air) pressure. They are classified as being fixed aligned or self aligning depending upon their ability to ensure a vertical pull-off force. Best repeatability is obtained when the pull-off force acts perpendicular to the surface being tested.

2.6.1.4 Scrape Tests

This test is typically performed in a laboratory and is limited to testing on smooth, flat panel surfaces. Adhesion is determined by pushing the coated panels beneath a rounded stylus or loop that is loaded in increasing amounts until the coating is removed

from the substrate surface. A device called a balanced-beam scrape-adhesion tester is used.

A standard method for the application and performance of this test is available in ASTM D2197.

2.6.1.5 Other Tests

There are many other adhesion tests. Some of these involve the use of tensile test machines with paint applied to the substrate with a textile strip embedded in the paint (the tensile machine pulls substrate and cloth) or have the paint applied between two sheets of the substrate (tensile machine pulls on both substrate pieces). ASTM D2370 describes one such test of elongation, tensile strength, and stiffness of organic films when tested as free films. Organic coating adhesion to plastic substrates by mounting an aluminum stud and removing it with a tensile tester is covered in ASTM D5179.

ASTM D4145 describes a bending test for determining flexibility and adhesion of coatings on prepainted metallic substrates. These organic coatings are subjected to stresses when fabricated into products by roll forming, brake bending, or other deformation processes. These stresses can exceed the flexibility or adhesive strength of the coating resulting in fracture of the coating, exposing the substrate, or loss of adhesion to the substrate. This test is a means of evaluating the ability of a coating system to withstand the stresses of fabrication.

Formability and adhesion testing of factory applied zinc-rich primer/chromate complex coatings on steel is described in ASTM 4146. In this test, a coated specimen is biaxially stretched a given distance in an appropriate machine, adhesive tape is applied to the deformed area (dome) and then pulled off, and the amount of coating removed is compared with a photographic standard to determine the coating adhesion rating.

Adhesion is also a measurable result of some hardness tests made by pencil hardness, gravelometer, impact (falling dart, etc.) or mandrel bend. Coating chip-off should be recorded during these tests. Finally, loss of adhesion can be noted during some chemical resistance tests where the coating blisters, bubbles up or even falls off.

2.6.2 Salt Spray Testing (ASTM B117)

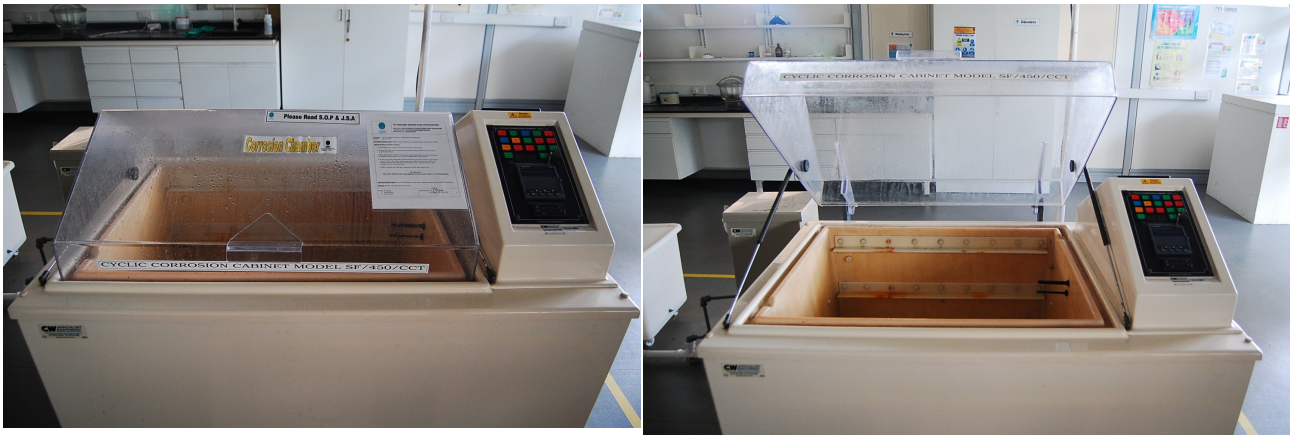


Figure 2.11: Salt Spray Chamber

The simplest and standardized method to check corrosion resistance of coated samples is via Salt Spray Testing. The main purpose of Coatings is to provide corrosion resistance to metallic parts made of carbon steel. Since coatings can provide a high corrosion resistance through the intended life of the part in use, it is necessary to check corrosion resistance by other means. The coated sample will run high speed of salt spray that produces corrosion attack in the salt spray chamber in the **figure 2.11**. After a period of time, the coated sample evaluated. The more corrosion resistant of coating the longer period of testing will be run to define the signs of corrosion.

The Chamber construction, testing procedure and testing parameters are standardized under national and international standards. In this experiment, ASTM B 117 standard is used. These standards describe the necessary information to carry out this test; testing parameters such as temperature, air pressure of the sprayed solution, preparation of the spraying solution, concentration, pH and others.

Daily checking of testing parameters is necessary to show compliance with the standards, so records shall be maintained accordingly. ASTM B 117 is widely used as reference standards worldwide. Testing cabinets are manufactured according to the specified requirements and here. However, these testing standards neither provide

information of testing periods for the coatings to be evaluated, nor the appearance of corrosion products in form of salts.

2.6.3 Simultaneous Differential Scanning Calorimetry & Thermogravimetric Analysis (DSC- TGA)

A simultaneous DSC-TGA device that can be used to characterize any material exhibiting a weight change or a phase change between ambient and 1500 ^{o}C.(i.e.); the mass of a substance and the difference in energy inputs into a substance and a reference material are both measured simultaneously as a function of temperature while the substance and reference material are subjected to a controlled temperature program. The **figure 2.12** shows overview of DSC-TGA equipment.

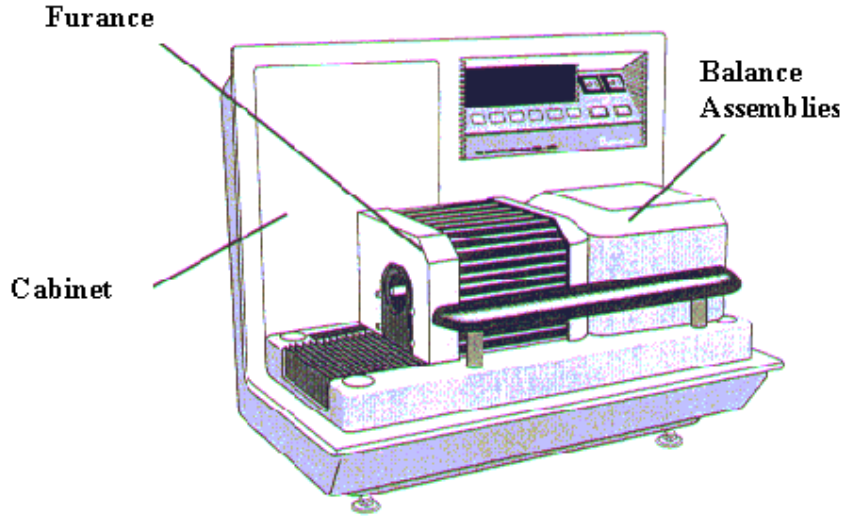


Figure 2.12: Simultaneous Differential Scanning Calorimetry & Thermogravimetric Analysis (DSC- TGA) Equipment.

2.6.4 Electrochemical Impedance Stereoscopic (EIS)

Impedance is a concept associated with the transmission of waves and electrical signals. There are many kinds of waves, and impedance is different in each of them, hence this disambiguation page. However, impedance is also a unifying concept. It is related to the load that is imposed on the source that generates a wave. It governs the reflection and transmission of wave's incident on a change of medium. If the impedances in the two media match, there will be no reflection. One simple approach

identifies two parameters for a wave: the restoring force that tries to return to equilibrium and the inertia of the medium displaced. Then the impedance is

Z = the square root of (restoring force) times (inertia)

While the velocity of the wave is

v = the square root of (restoring force) divided by (inertia)

For example, for a sound wave the restoring force is the modulus of elasticity, while the inertia is just the density. For some waves (light waves, for example) it is not obvious how this simple picture for mechanical waves can be applied, but the same general picture holds.

Electrochemical measurement were used for understanding and explaining the changes in the coating of polymer coated steel during sterilization, and the corrosion mechanism observed visually in the saline sterilization test. Capacity and electrochemical impedance spectroscopy measurement showed coating property changes during sterilization. Improved product performance due to heat pre-treatment before filling and sterilization could also be explained with electrochemical measurements. The electrochemical measurements showed to be a powerful tool in understanding the mechanisms involved in product deterioration.

Electrochemical Impedance Stereoscopic can generate quantitative data that relates to the quality of a coating on a metal substrate. It is probing the energy storage and dissipation over range of frequencies by means of impedance. Impedance is the opposition to the flow of alternating current (AC) in a complex system. A passive complex electrical system comprises both energy dissipater (resistor) and energy storage (capacitor) elements. If the system is purely resistive, then the opposition to

AC or direct current (DC) is simply resistance. Almost any physico-chemical system, such as electrochemical cells, mass-beam oscillators, and even biological tissue possesses energy storage and dissipation properties. EIS examines them. EIS is a very sensitive detector of the condition of a coated metal, so the EIS response can indicate

changes in the coating long before any visible damage occurs. **Figure 2.13** is referring to the overview of sample conducted with EIS testing.

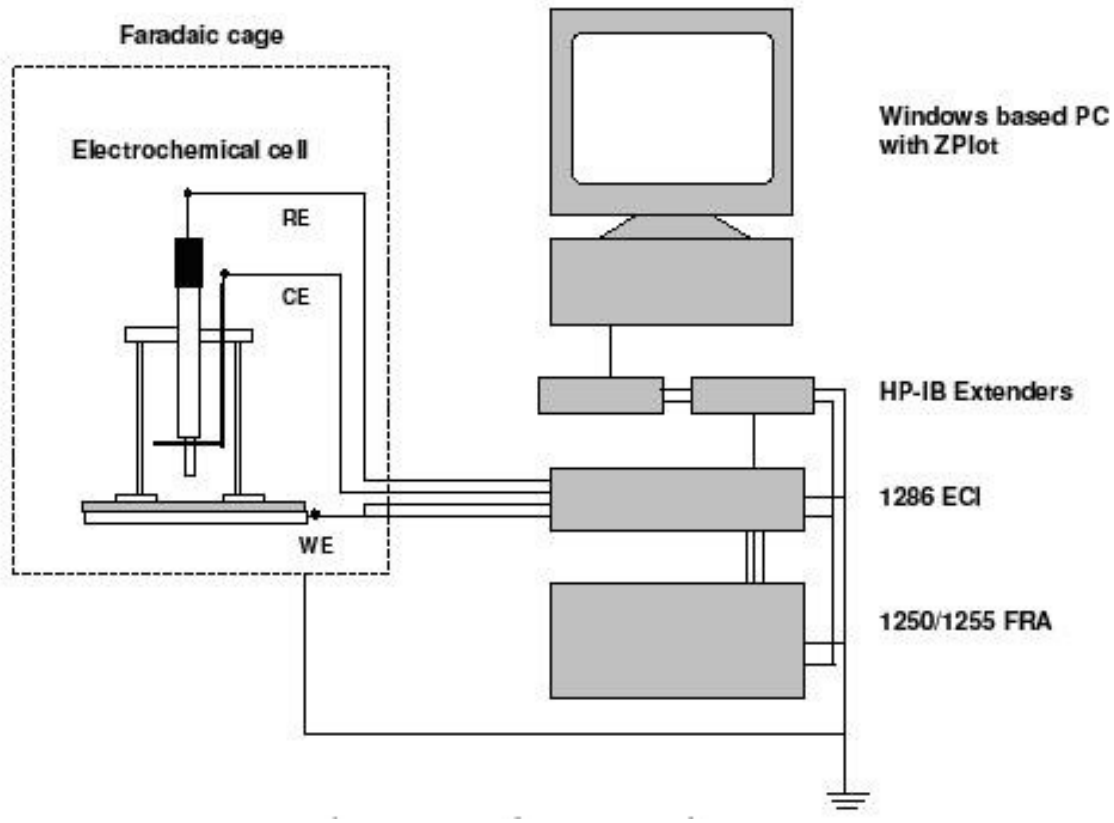


Figure 2.13: Overview of the set up used for electrochemical measurement at intact model [2]

More coating performance tests please refer the **appendix 1**.

CHAPTER 3
METHODOLOGY

The methodology in this project was designed to study the corrosion prevention behavior of tapioca polysaccharides based – coating (TPS).It shown in the figure 3.1 below.

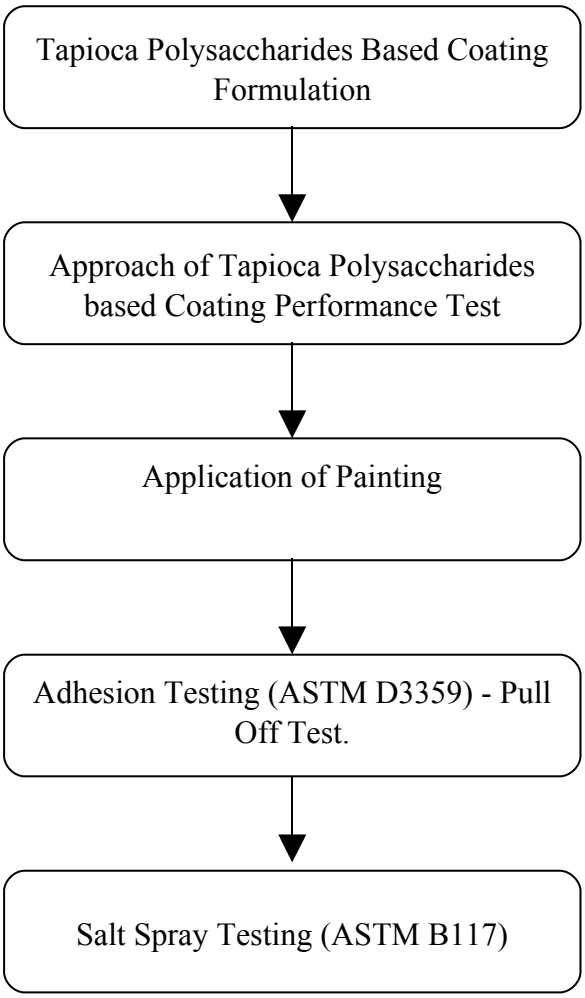


Figure 3.1: The project methodology.

3.1 Tapioca Polysaccharides Based Coating Formulation

The tapioca polysaccharides based-coating was made by the formulation of tapioca polysaccharides powder and epoxy resin which is Epolam 2050. The author was using the "try and error method" to find the best paint formulation of tapioca polysaccharides based coating (TPS).The TPS is cheaper than epolam 2050. So the more TPS in the paint formulation will decrease the production cost of the coating.

The formula of paint formulation calculation:

Weight Epolam = We

Weight TPS = Wtps

Weight Hardener = Wh

We = Ratio of Weight Epolam 2050 to TPS x 5.0 g

Wtps = Ratio of TPS to Epolam 2050 x 5.0 g

Wh = Ratio of Hardener to Epoxy (0.32) x We

Example Calculation of Sample A with ratio 05:95 = Wtps : We

We = 0.95% x 5.00g = 4.75g

Wtps = 0.05% x 5.00g = 0.25g

Wh = 0.32% x 4.75g = 1.52g

All the 10 samples were formulated using the same calculation formula above and the result shown in the tables 3.1,3.2,3.3,3.4,3.5,3.6,3.7,3.8,3.9,3.10 and figures 3.2,3.3,3.4,3.5,3.6,3.7,3.8,3.9,3.10,3.11.

Sample A was calculated using the formula explained earlier. Table 3.1 show the weight of epolam 2050, tapioca polysaccharides powder and hardener.

Table 3.1: Tapioca Polysaccharides Coating Sample A

Sample of Coating 1: (05:95)

No	Item	Weight (g)
1	Epolam 2050	4.75g
2	Tapioca Polysaccharides powder	0.25g
3	Hardener	1.52g

The result of the Sample A formulation is referring to figure 3.2 .It produced glossy, less viscosity and good mixable rate solution of tapioca polysaccharides based coating.

Figure 3.2: Sample A (TPS 05%: EPOLAM 2050 95%)

The sample B was calculated using the formula explained earlier. Table 3.2 show the weight of epolam 2050, tapioca polysaccharides powder and hardener.

Table 3.2: Tapioca Polysaccharides Coating Sample B

Sample of Coating 2: (10:90)

No	Item	Weight (g)
1	Epolam 2050	4.50g
2	Tapioca Polysaccharides powder	0.50g
3	Hardener	1.44g

The result of the Sample B formulation is referring to figure 3.3 . It produced glossy, less viscosity and good mixable solution of tapioca polysaccharides based coating.

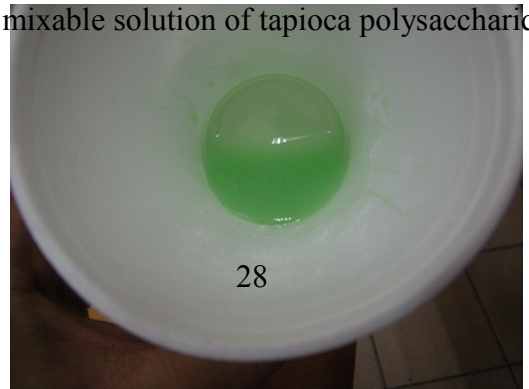


Figure 3.3: Sample B (TPS 10%: EPOLAM 2050 90%)

The sample C was calculated using the formula explained earlier. Table 3.3 show the weight of epolam 2050, tapioca polysaccharides powder and hardener.

Table 3.3: Tapioca Polysaccharides Coating Sample C

Sample of Coating 3: (15:85)

No	Item	Weight (g)
1	Epolam 2050	4.25g
2	Tapioca Polysaccharides powder	0.75g
3	Hardener	1.36g

The result of the Sample C formulation is referring to figure 3.4 . It produced glossy, less viscosity and good mixable solution of tapioca polysaccharides based coating.

Figure 3.4: Sample C (TPS 15%: EPOLAM 2050 85%)

The sample D was calculated using the formula explained earlier. Table 3.4 show the weight of epolam 2050, tapioca polysaccharides powder and hardener.

Table 3.4: Tapioca Polysaccharides Coating Sample D

Sample of Coating 4: (20:80)

No	Item	Weight (g)
1	Epolam 2050	4.00g

2	Tapioca Polysaccharides powder	1.00g
3	Hardener	1.28g

The result of the Sample D formulation is referring to figure 3.5 . It produced glossy, medium viscosity and good mixable solution of tapioca polysaccharides based coating.

Figure 3.5: Sample D (TPS 20%: EPOLAM 2050 80%)

The sample E was calculated using the formula explained earlier. Table 3.5 show the weight of epolam 2050, tapioca polysaccharides powder and hardener.

Table 3.5: Tapioca Polysaccharides Coating Sample E

Sample of Coating 5: (25:75)

No	**Item**	**Weight (g)**
1	Epolam 2050	3.75g
2	Tapioca Polysaccharides powder	1.25g
3	Hardener	1.25g

The result of the Sample E formulation is referring to figure 3.6 . It produced glossy, medium viscosity and good mixable solution of tapioca polysaccharides based coating.

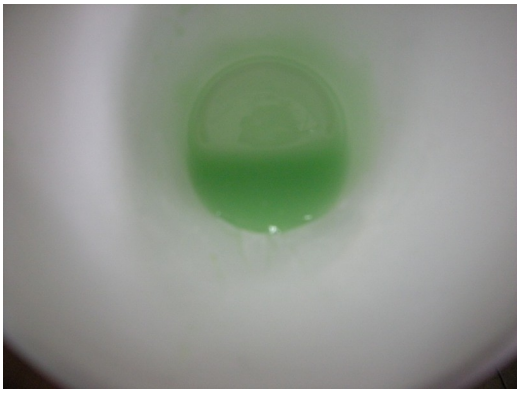


Figure 3.6: Sample E (TPS 25%: EPOLAM 2050 75%)

The sample F was calculated using the formula explained earlier. Table 3.6 show the weight of epolam 2050, tapioca polysaccharides powder and hardener.

Table 3.6: Tapioca Polysaccharides Coating Sample F

Sample of Coating 6: (30:70)

No	Item	Weight (g)
1	Epolam 2050	3.50g
2	Tapioca Polysaccharides powder	1.50g
3	Hardener	1.12g

The result of the Sample F formulation is referring to figure 3.7 . It produced glossy, medium viscosity and good mixable solution of tapioca polysaccharides based coating.

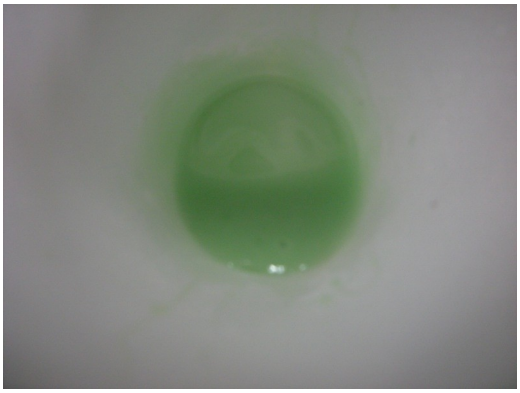


Figure 3.7: Sample F (TPS 30%: EPOLAM 2050 70%)

The sample G was calculated using the formula explained earlier. Table 3.7 show the weight of epolam 2050, tapioca polysaccharides powder and hardener.

Table 3.7: Tapioca Polysaccharides Coating Sample G

Sample of Coating 7: (35:65)

No	Item	Weight (g)
1	Epolam 2050	3.25g
2	Tapioca Polysaccharides powder	1.75g
3	Hardener	1.04g

The result of the Sample G formulation is referring to figure 3.8 . It produced glossy,

medium viscosity and good mixable solution of tapioca polysaccharides based coating.

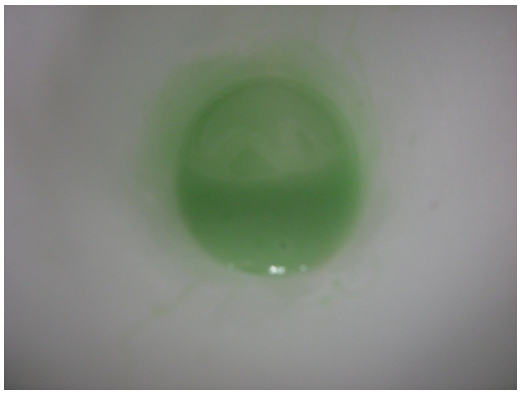


Figure 3.8: Sample G (TPS 35%: EPOLAM 2050 65%)

The sample H was calculated using the formula explained earlier. Table 3.8 show the weight of epolam 2050, tapioca polysaccharides powder and hardener.

Table 3.8: Tapioca Polysaccharides Coating Sample H

Sample of Coating 8: (40:60)

No	Item	Weight (g)
1	Epolam 2050	3.00g
2	Tapioca Polysaccharides powder	2.00g
3	Hardener	0.96g

The result of the Sample H formulation is referring to figure 3.9 . It produced matt, high viscosity and bad mixable solution of tapioca polysaccharides based coating

Figure 3.9: Sample H (TPS 40%: EPOLAM 2050 60%)

The sample I was calculated using the formula explained earlier. Table 3.9 show the weight of epolam 2050, tapioca polysaccharides powder and hardener.

Table 3.9: Tapioca Polysaccharides Coating Sample I

Sample of Coating 9: (45:55)

No	Item	Weight (g)
1	Epolam 2050	2.75g
2	Tapioca Polysaccharides powder	2.25g
3	Hardener	0.88g

The result of the Sample I formulation is referring to figure 3.10 . It produced matt, high viscosity and bad mixable solution of tapioca polysaccharides based coating

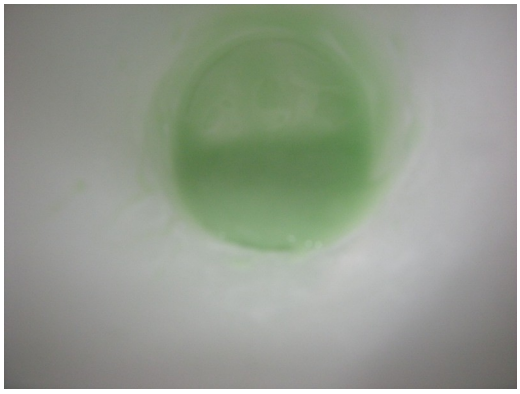


Figure 3.10: Sample I (TPS 45%: EPOLAM 2050 55%)

The sample J was calculated using the formula explained earlier. Table 3.10 show the weight of epolam 2050, tapioca polysaccharides powder and hardener.

Table 3.10: Tapioca Polysaccharides Coating Sample J

Sample of Coating 10: (50:50)

No	Item	Weight (g)
1	Epolam 2050	2.50g
2	Tapioca Polysaccharides powder	2.50g
3	Hardener	0.80g

The result of the Sample J formulation is referring to figure 3.11 . It produced matt, high viscosity and bad mixable solution of tapioca polysaccharides based coating

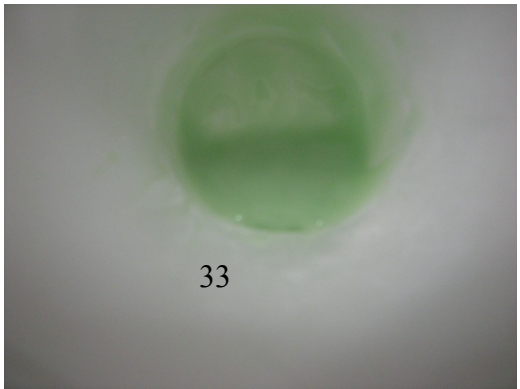
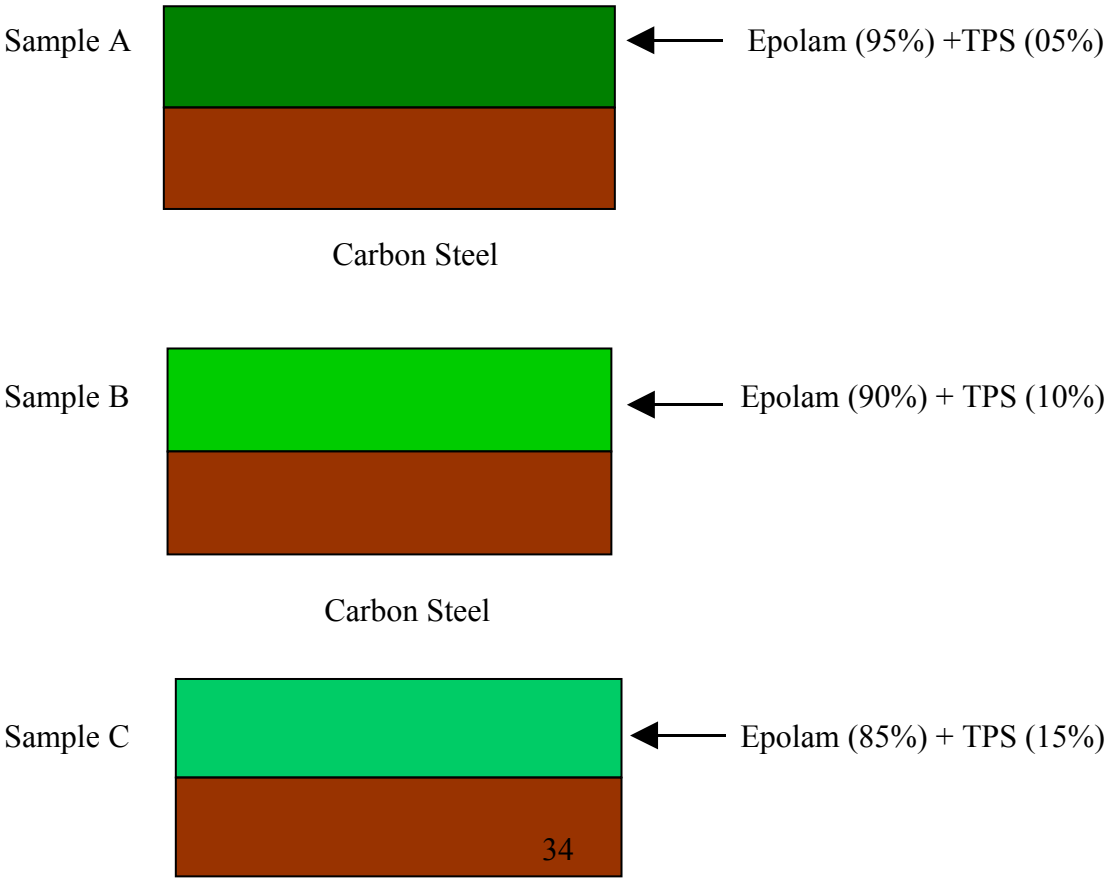


Figure 3.11: Sample J (TPS 50%: EPOLAM 2050 50%)

The top 3 best samples choose in term of good mix ability, the viscosity and stable paint formulation which is sample A, B and C.

3.2 Approach of Tapioca Polysaccharides based Coating Performance Test

To study the tapioca polysaccharides based coating anti corrosive behavior, it will be coated onto the test panel which are carbon steel plates. The "Intact model" shown in the figure 3.12 will be used as the approach. Three carbon steel plates represented 3 samples of coating with different paint formulation and will be conducted with coating performance test by salt spray and adhesion testing.



Carbon Steel

Figure 3.12: Schematic View of the build up of “intact model” coating samples. [2]

3.3 Application of painting

1- 3 samples of tapioca polysaccharides based coating and hardener were mixed for 3-5 minutes.

2- By Measuring 1: 0.32 (base on hardener) both solution were mixed together.

3- By brush, the paint was applied onto the test panel which is carbon steel plate surface.

4- All the painted test panel was let dried at room at least three days before conducted with coating performance test.

5- Dry Film Thickness (DFT) calibration was taken after drying period.

3.3.1 Coating Surface Preparation

Surface preparation is the most important part of a coating system, because it affects the performance of the coating more than any other variable. Given that the correct coating system is selected, if the surface preparation is poor, coating performance is usually going to be poor. If surface preparation is good, then the coating applied over it is likely to perform well.

When a surface is very smooth, coatings have a difficult time adhering strongly. A scraper or even a fingernail, for instance, easily removes a coating on glass. On the other hand it is difficult to remove a coating on a rough surface like sandpaper. Steel, when it is abrasive blasted, has a surface that is rough like sandpaper, with a series of tiny peaks and valleys called surface profile shown in the figure 3.13. Coatings anchor themselves to the valleys of the profile, and the peaks are like teeth. This is why surface profile created by blasting is sometimes called an "anchor pattern" or "mechanical tooth."

Surface preparation creates a foundation in two important ways:

1. Mechanical way, by providing an anchor for the coating.
2. Chemical way, by allowing intimate contact of coating material molecules with the steel (or other material) surface.

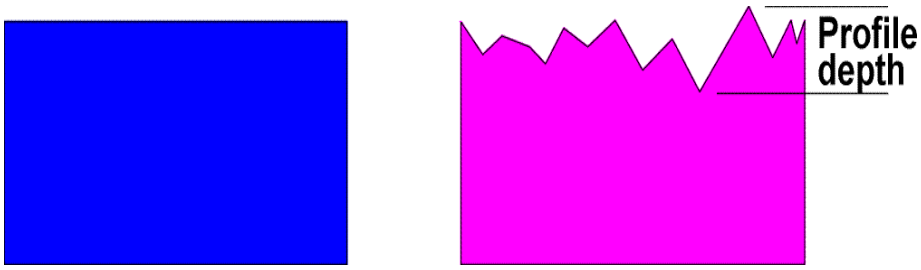


Figure 3.13: The Surface Profile in Surface Preparation

3.3 Adhesion Test (ASTM D3359) - Pull Off Test

Figure 3.14: Dollies Attached and Detached from Test Panel for Adhesion Test

A quantitative test for adhesion is the pull-off test where a loading fixture, commonly called a dolly or stub, is affixed by an adhesive to a coating. The adhesion testing conducted is shown in the figure 3.14 above where the dollies attached and detached from the test panel. By use of a portable pull-off adhesion tester, a load is increasingly applied to the surface until the dolly is pulled off. The force required pulling the dolly off or the force the dolly withstood yields the tensile strength in pounds per square

inch (psi) or mega Pascals (MPa). Failure will occur along the weakest plane within the system comprised of the dolly, adhesive, coating system, and substrate, and will be exposed by the fracture surface.

This test method maximizes tensile stress as compared to the shear stress applied by other methods, such as scrape or knife adhesion, and results may not be comparable. Further, pull-off strength measurements depend upon the instrument used in the test. Results obtained using different devices or results for the same coatings on substrates having different stiffness may not be comparable.

Testers operate using mechanical (twist by hand), hydraulic (oil) or pneumatic (air) pressure. They are classified as being fixed aligned or self aligning depending upon their ability to ensure a vertical pull-off force. Best repeatability is obtained when the pull-off force acts perpendicular to the surface being tested

3.4 Salt Spray Testing (ASTM B117)

Apparatus

The apparatus for required for salt spray (fog) exposure consists of a

1-Fog chamber,

2-Salt spray solution reservoir

3-Supply of suitably conditioned compressed air

4-One or more atomizing nozzles

5-Specimens supports

6- Provision for heating the chamber and necessary means of control.

Preparation of Test Sample

1-Samples shall be suitably cleaned. The cleaning method shall be optional depending on the nature of the surface and the contaminants.

2-Sample for evaluation of paints shall be prepared in accordance with applicable specifications such as the material time of being exposed and etc.

3-Specimen coated with paints shall not be cleaned

4-Whenever it is desired to determine the development of corrosion from an abraded area in the paint, a scratch or scribed line shall be made through the coating with a sharp instrument.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Tapioca Polysaccharides Based Coating Formulation

The first objective of this study is not the development of optimal coating but the study of behavior of the tapioca polysaccharides. Therefore, the sample coatings have been based on a binder, without adding the necessary additions to give the coating mores extra benefits. The tapioca based coating then ready to use on the carbon steel plates.

The first step of experiment is to formulate stabile and mixable tapioca polysaccharides based coating according to the correct paint formulation. The based coating contains was tapioca polysaccharides powder, epoxy resin and hardener. There are 3 best samples of polysaccharides coating have been chosen. Each sample of coating was formulated with different amount of epoxy resin and tapioca polysaccharides powder as specific ratio shown in the table 4.1 , 4.2, 4.3.

The coating of sample A was selected because of the good mixable solution with epolam 2050 and the tapioca polysaccharides. The composition of the epolam 2050 and tapioca polysaccharides weight are shown in the table 4.1.

Table 4.1: Tapioca Polysaccharides Coating Sample A

Sample of Coating 1: (05:95)

No	Item	Weight (g)
1	Epolam 2050	4.75g
2	Tapioca Polysaccharides powder	0.25g
3	Hardener	1.52g

The sample A refers figure 4.1 produce a glossy, wet, low viscosity and good mixable

rate of solution.

Figure 4.1: Tapioca Polysaccharides Based Coating Sample A (TPS 5%: EPOLAM 2050 95%)

The coating of sample B was selected because of the good mixable solution with the epolam 2050 and the tapioca polysaccharides. The composition of the epolam 2050 and tapioca polysaccharides weight are shown in the table 4.2.

Table 4.2: Tapioca Polysaccharides Coating Sample B

Sample of Coating 2: (10:90)

No	Item	Weight (g)
1	Epolam 2050	4.50g
2	Tapioca Polysaccharides powder	0.50g
3	Hardener	1.44g

The sample B refers figure 4.2 produce a glossy, wet, low viscosity and good mixable rate of solution.

Figure 4.2: Tapioca Polysaccharides Based Coating Sample B (TPS 10%: EPOLAM 2050 90%)

The coating of sample C was selected because of the good mixable solution with the epolam 2050 and the tapioca polysaccharides. The composition of the epolam 2050 and tapioca polysaccharides weight are shown in the table 4.3.

Table 4.3: Tapioca Polysaccharides Coating Sample C

Sample of Coating 3: (15:85)

No	Item	Weight (g)
1	Epolam 2050	4.25g
2	Tapioca Polysaccharides powder	0.75g
3	Hardener	1.36g

The sample C refers figure 4.3 produced a glossy, wet, low viscosity and good mixable rate of solution. When the composition of TPS is more than 25% the solution will become matt, high viscosity and also bad mixable solution. At the composition of TPS 50% the coating become very matt, hard and bad mixable rate and it show the limit of the polymer blends between the TPS and Epolam 2050.

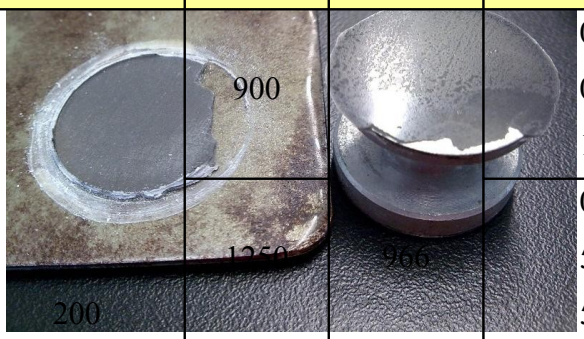
Figure 4.3: Tapioca Polysaccharides Based Coating Sample C (TPS 15%: EPOLAM 2050 75%)

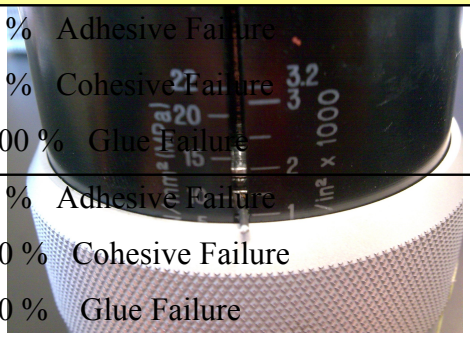
4.2 Adhesion Test (ASTM D3359)

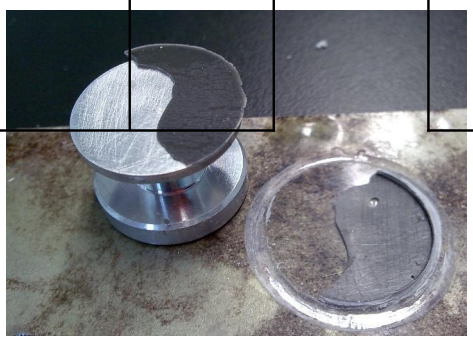
The second testing was adhesion testing to determine the ability of coating to substrates on which they are applied.

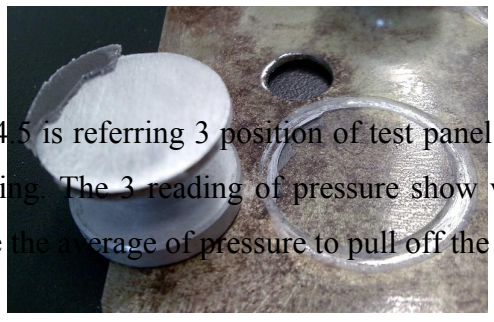
Table 4.5: Details of Pull-off Adhesion Test Results

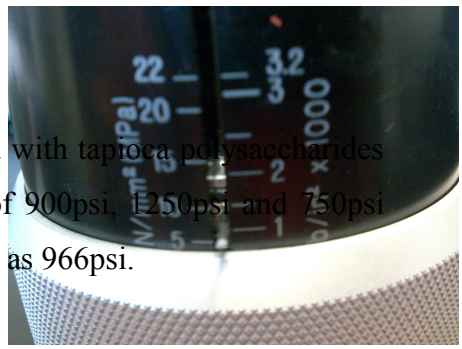
Position	Failure Modes			Pressure Reading
Dolly Position	Acceptance Criteria (Psi)	Strength (Psi)	Average (Psi)	Failure Modes
1	200	900	966	0 % Adhesive Failure 0 % Cohesive Failure 100 % Glue Failure
2		1250		0 % Adhesive Failure 50 % Cohesive Failure 50 % Glue Failure
3		100% glue failure		0 % Adhesive Failure 0 % Cohesive Failure 100 % Glue Failure
		750		
2		50% cohesive failure 50% glue failure		1250 psi
3		100% glue failure		750 psi











The table 4.5 is referring 3 position of test panel coated with tapioca polysaccharides based coating. The 3 reading of pressure show value of 900psi, 1250psi and 750psi which give the average of pressure to pull off the dollies as 966psi.

Table 4.6: Pull off Adhesion Test Result

After conducted with pull off method testing, all the dollies were pulled out at the average pressure 966 psi which is higher than **200 psi** as stated in the table 4.6 as per acceptance criteria used in the oil and gas industries application. This concludes that the test results are acceptable until the coating experience bond failure either adhesive (failure at the coating / substrate interface) or cohesive failure (failure within the coating film or the substrate).

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4.3 Salt Spray Testing (ASTM B117)

With reference to all concepts elaborated in Chapter 2, some findings were made after considering all parameters involved with the samples were evaluated. The samples

were subjected to testing in a salt spray cabinet and followed as maximum procedure in the ASTM B117 test methods.

Although the testing is unable to give an actual life expectancy relative to the accelerated salt spray testing, Author does feel it gives you a good relative test when compared to other competitive products.

Figure 4.4, 4.5 and 4.6 are the comparison between the coated carbon steel and also uncoated one. The coated carbon steel provides glossy, wet and a layer of protection from corrosion attack.

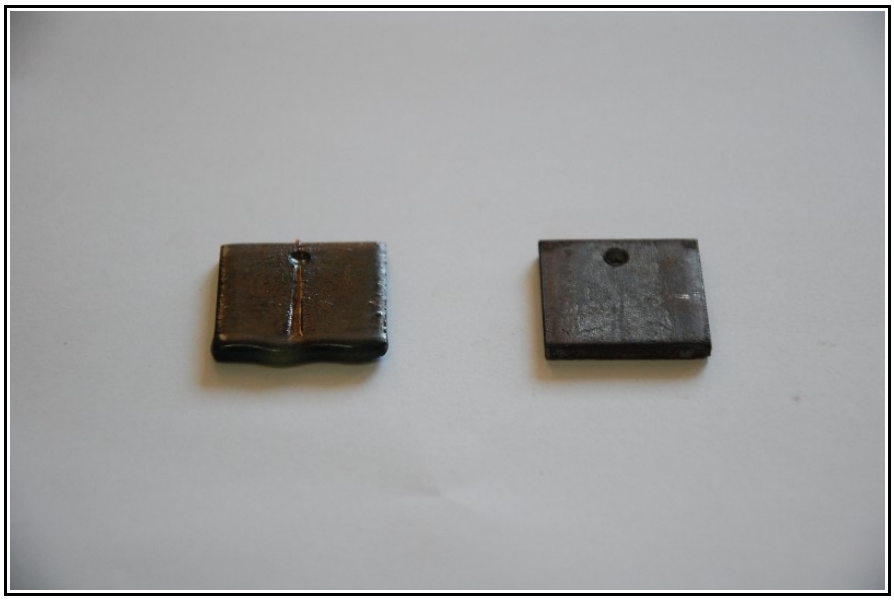

Figure 4.4: Sample A before Salt Spray Testing (05% Tapioca Polysaccharides + 95% Epolam 2050)

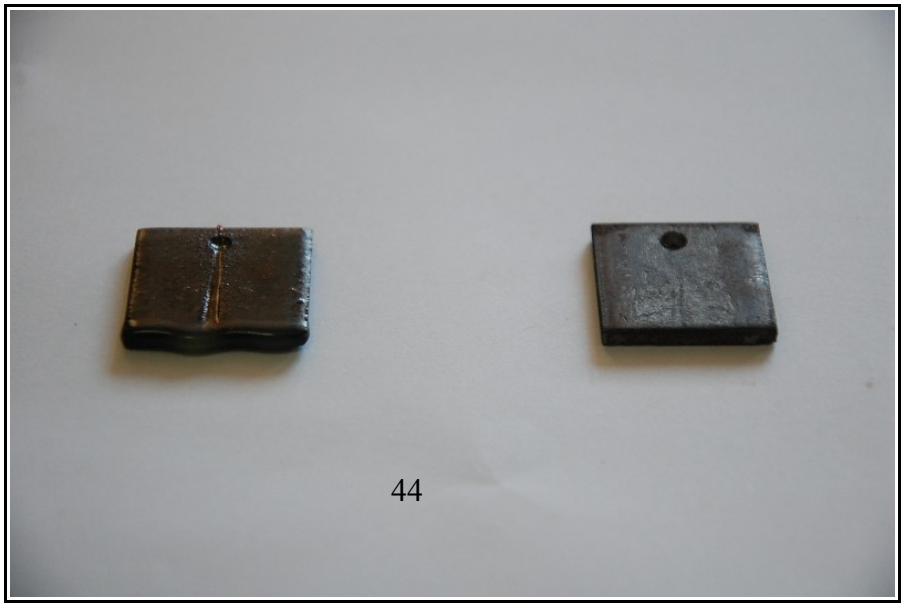

Figure 4.5: Sample B before Salt Spray Testing (10% Tapioca Polysaccharides + 90% Epolam 2050)

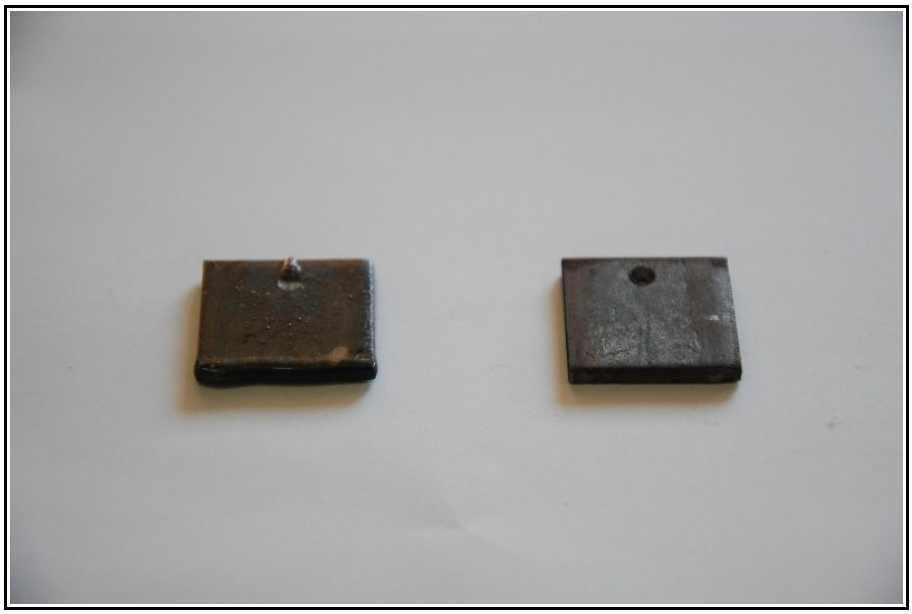

Figure 4.6: Sample C before Salt Spray Testing (15% Tapioca Polysaccharides + 85% Epolam 2050)

The coated samples was exposed to the high speed of salt spray for 168 hours and the result of the sample shown in the table 4.4

Table 4.4: The Salt Spray Result

No.	Sample	FINISH

1	A (05:95)	Surface slightly discolored with white residue
2	B (10:90)	Surface slightly discolored with white residue
3	C (15:95)	Less amount of white residue.

After testing the Sample A, B, and C for 168 hours using Test ASTM B1117 the following observations are noted in the figure 4.7, 4.8 and 4.9.

Referring to the sample A ,B and C at figure 4.7 , 4.8 ,4.9 there are no rust at the part where it coated with the TPS based coating. Only the white residue and discolored occurred cause by the salt solution sprayed on to the test panel.

Figure 4.7: Samples A after salt spray testing

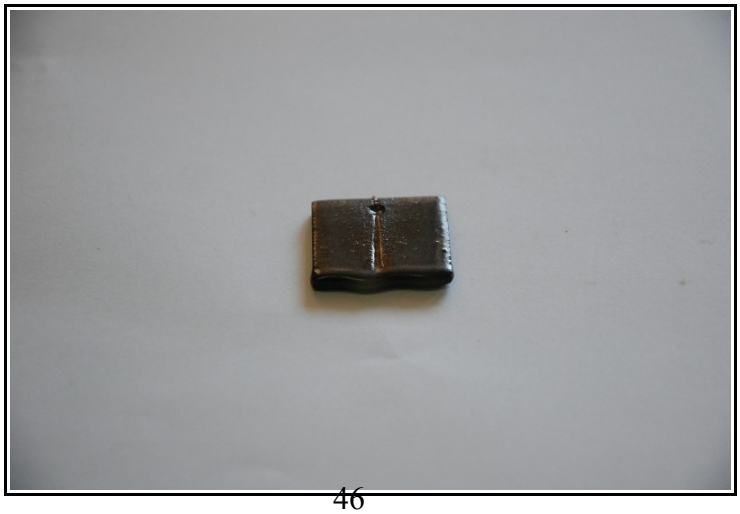

Figure 4.8: Samples B after salt spray testing

Figure 4.9: Samples C after salt spray testing

Surface preparation is important step before coating is applied to the carbon steel plates. If the surface preparation is poor, coating performance is usually going to be poor. If surface preparation is good, then the coating applied over it is likely to perform well. The standard procedures were followed to ensure best result for the coating.

The second testing was to determine the corrosion resistance by visual inspection. All the coated carbon steel plates were placed in the salt spray chamber and provided with continuous corrosion attack for 168 hours. The configuration of the corrosion is referring to the ASTM B117. The evaluation of coated plates subjected to corrosive is using ASTM D 1654. From the observation, carbon steel plates were not corroded and the tapioca polysaccharides coating show anti corrosion behaviors to protect the carbon steel.

CHAPTER 5
CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

The tapioca polysaccharides based coating formulated by mix the epolam 2050 and tapioca polysaccharides powder with specific amount of weight according to the theory of polymer blends. Good composition is obtained with 85%epoxy and 15% TPS.

Based on salt spray testing, the coating show satisfactory performance against corrosion with an average result which is above the acceptable industry standard. The adhesion testing to determine the how good is the coating to substrates on which they are applied. Tapioca polysaccharide based coating show it ability to resist within the allowable range of pressure during the pull off test and good bond on the carbon steel plates.

In conclusion, the tapioca polysaccharides coating show anti corrosive behavior and has a good adhesion .Besides , it provide another alternative for green technology implementation in coating industries which not only protecting the steel from corrosion but also the environment and safe for human's life.

3.6 Recommendations

The recommendation for this project, since the tapioca polysaccharides made own by the author are polysaccharide-based extract, so the quality of pure polysaccharides can be enhanced using the latest technology of extraction. The pure polysaccharides used in the coating hopefully it can increase the ability to protect carbon steel from corrosion.

In order to define the corrosion protective behaviour of tapioca polysaccharides coating, many more coating testing can be conducted besides the testing selected in the project such as Electrochemical Impedance Stereoscopic Testing and Simultaneous Differential Scanning Calorimetry & Thermogravimetric Analysis (DSC- TGA) and many more.

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